

PHENIX RESULTS ON LOW-MASS DILEPTONS IN AU+AU COLLISIONS WITH THE HADRON BLIND DETECTOR



**Mihael Makek (University of Zagreb)
for the PHENIX Collaboration**



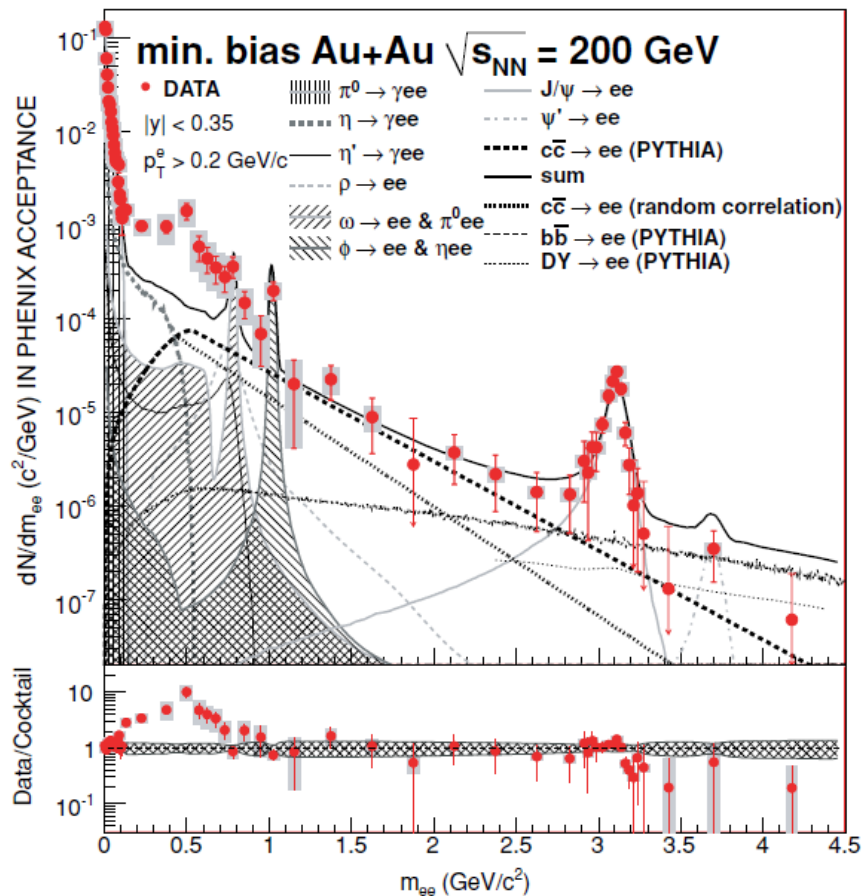
Quark Matter 2015, Kobe, 2015

Outline

- Introduction
- The Hadron Blind Detector
- Analysis
 - ▣ Electron identification
 - ▣ Background subtraction
 - ▣ Cocktail of hadronic sources
- Results
- Comparison to model
- Summary

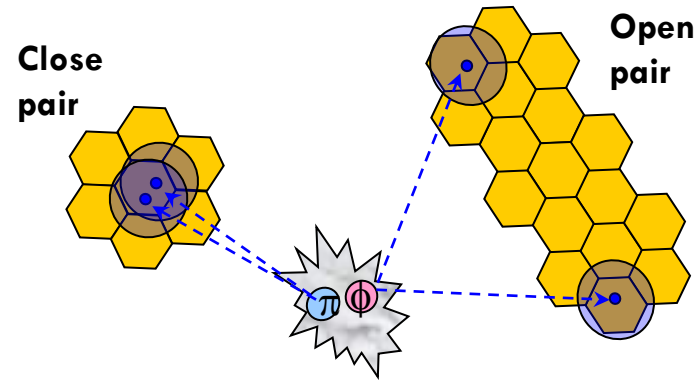
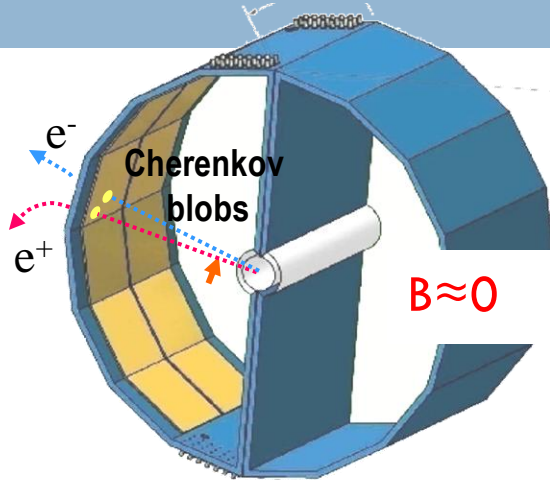
Introduction

PRC 81, 034911(2010)

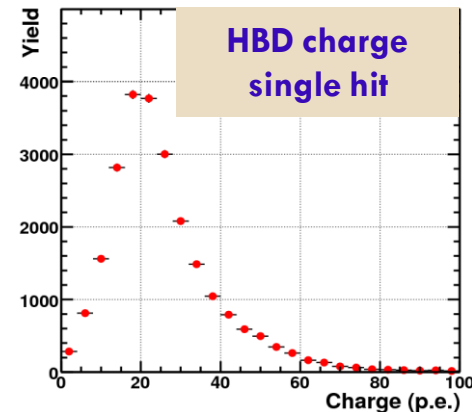
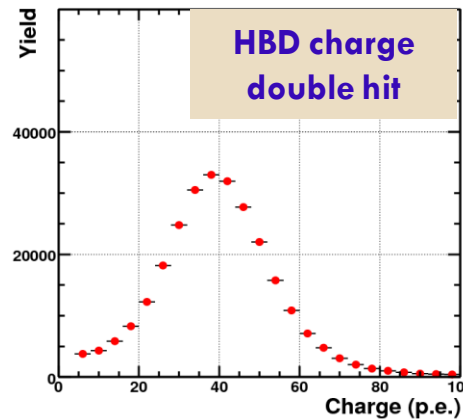


- In RHIC Run-4 PHENIX observed a large e^+e^- enhancement in the low mass region
 - Could not be explained by the models
- STAR observed much smaller enhancement (RHIC Run-10) PRL113 022301 (2014)
- A new PHENIX measurement in RHIC Run-10 with the Hadron Blind Detector to:
 - Reduce the hadron contamination
 - Improve the signal sensitivity

The Hadron Blind Detector



- Cherenkov detector using GEMs with CsI photocathode and CF_4 in a windowless configuration
 - ▣ Provides hadron rejection
 - ▣ Adds to eID capabilities
 - ▣ Suppresses bckg. e^+e^- pairs from π^0 Dalitz and γ conversions by their opening angle
 - ▣ Operates in magnetic field free region



NIM A646, 35-58 (2011)

Analysis

Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV
RHIC Run-10

Electron identification

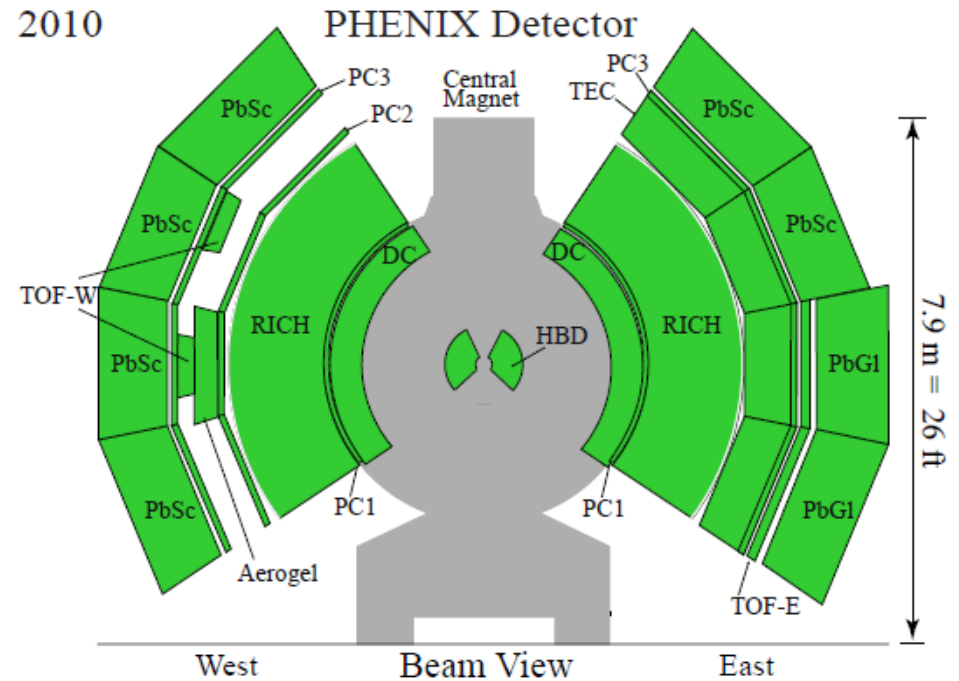
Background subtraction

Cocktail of hadronic sources



Electron identification with neural networks

- RICH
- EMCAL
- HBD
- TOF
 - ▣ EMCAL
 - ▣ TOFE



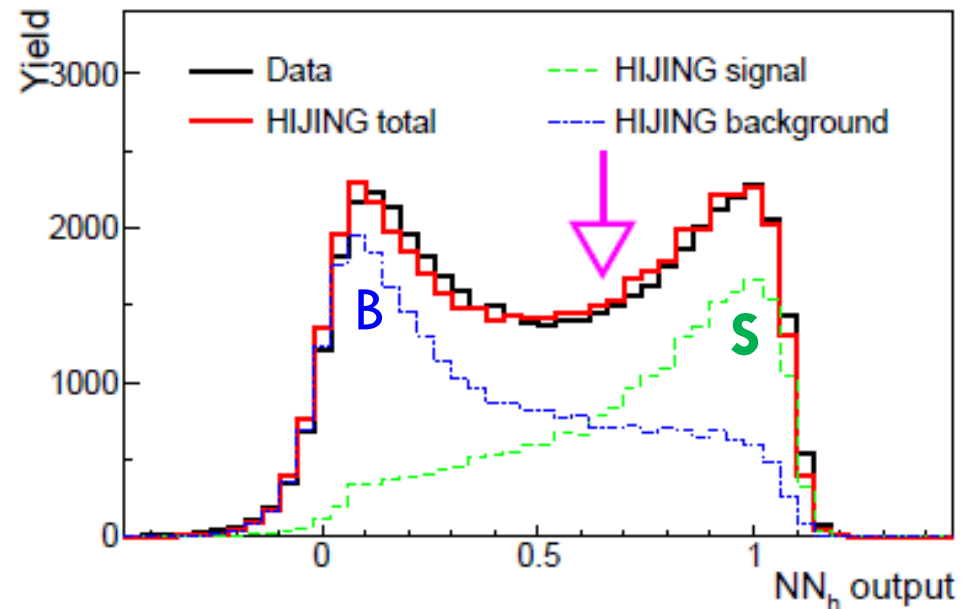
Electron identification with neural networks

- RICH
- EMCAL
- HBD
- TOF
 - EMCAL
 - TOFE

Total 14
eID parameters:

- Use as inputs to **neural networks**
- NNs trained and monitored by simulations
- **Achieve electron sample purity for all centralities $\geq 95\%$**

Example NN output for 0-10% centrality



Analysis

Electron identification

Background subtraction

Cocktail of hadronic sources



Background subtraction

Strategy – subtract component by component:

□ Traditional approach:

Total BG = mixed BG }
 + jet pairs }
 + cross-pairs }

combinatorial

correlated

→ could not reproduce the shape of the like-sign foreground

→ essential elements missing

Background subtraction

Strategy – subtract component by component:

□ Traditional approach:

Total BG = mixed BG } **combinatorial**
+ jet pairs } **correlated**
+ cross-pairs }

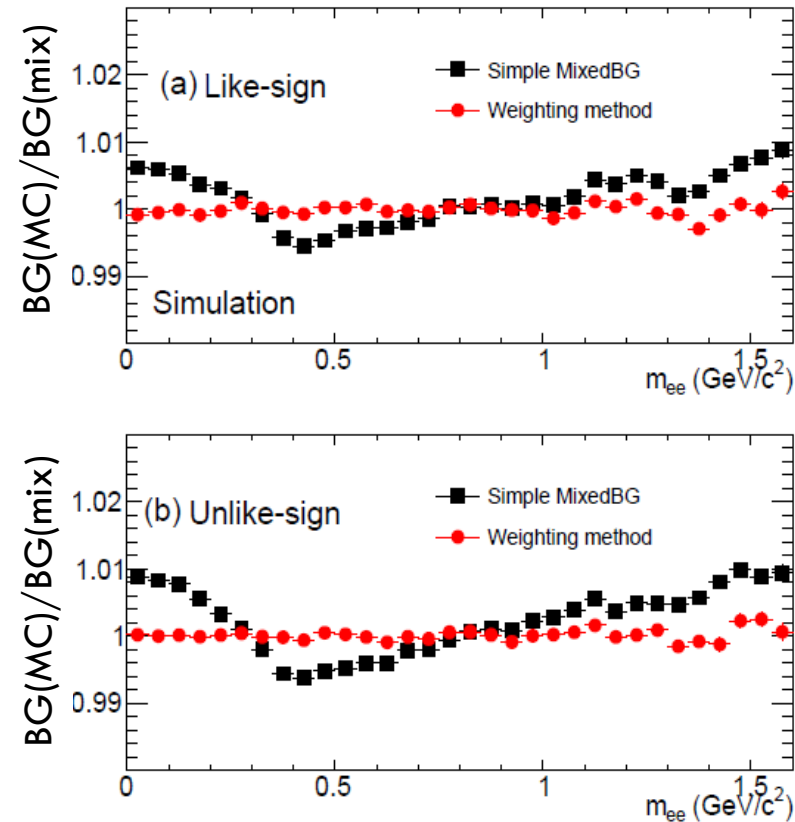
→ could not reproduce the shape of the like-sign foreground

→ essential elements missing

□ New approach:

Total BG = **mixed BG with flow modulation** } **combinatorial**
+ jet pairs } **correlated**
+ cross-pairs } **correlated**
+ **e-h pairs** }

Mixed background with flow modulation

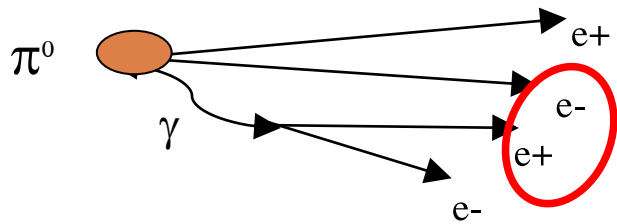


arXiv:1509.04667

- Flow distorts the shape of the combinatorial background
- To correct for the flow effect, each mixed BG pair is weighted by an analytic factor:

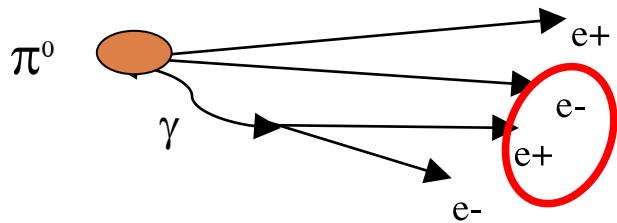
$$w(\Delta\phi) = 1 + 2 v_2(p_{T,1}) v_2(p_{T,2}) \cos(2\Delta\phi)$$
 - Inclusive single electron v_2 from the data
- The approach is verified by the simulation (plots on the left)
- The weighting method reproduces correctly the combinatorial background shape

Cross-pairs and jet pairs



- Simulated with EXODUS:
 $\pi^0 \rightarrow e^+ e^- \gamma$, $\pi^0 \rightarrow \gamma \gamma$ and $\eta \rightarrow e^+ e^- \gamma$, $\eta \rightarrow \gamma \gamma$
- Normalization: **absolute**
 - ▣ π^0 and η measured by PHENIX

Cross-pairs and jet pairs



- Simulated with EXODUS:
 $\pi^0 \rightarrow e^+e^-\gamma$, $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow e^+e^-\gamma$, $\eta \rightarrow \gamma\gamma$
- Normalization: **absolute**
 - ▣ π^0 and η measured by PHENIX

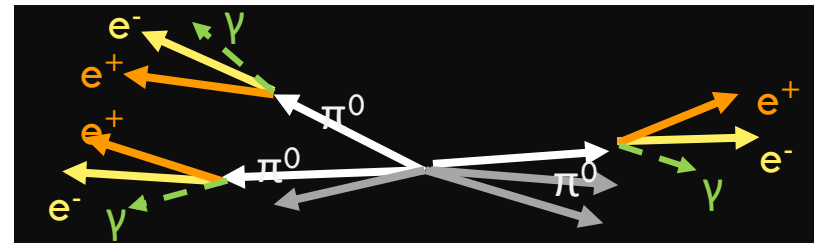
- Simulated with PYTHIA (p+p jets)

- Normalization: **absolute**

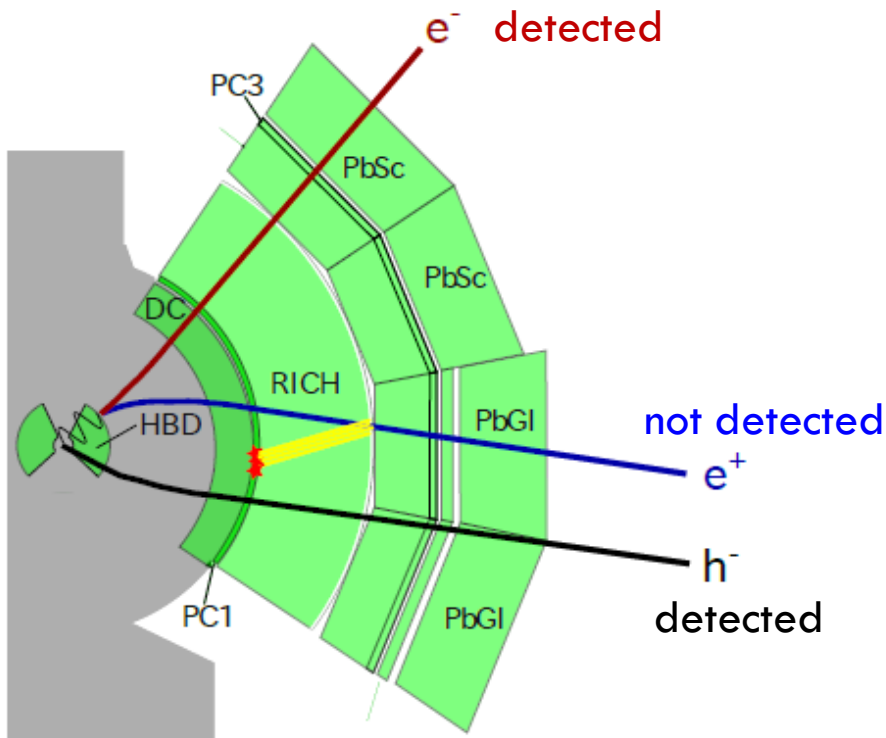
- ▣ Each ee pair scaled by:

$$N_{\text{coll}} * R_{\text{AA}}(p_T^a) * I_{\text{AA}}(p_T^b, \Delta\phi)$$

- p_T and $\Delta\phi$ refer to primary particles
- a – the particle with the higher p_T , b – the particle with the lower p_T
- R_{AA} and I_{AA} from PHENIX measurements



e-h pairs



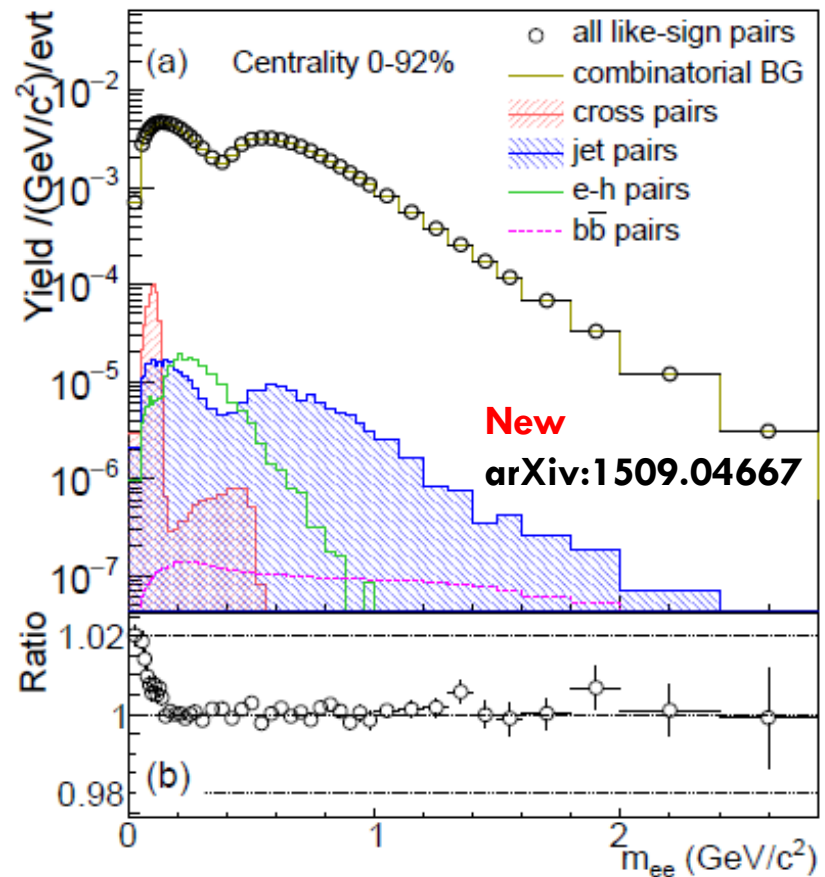
- RICH spherical mirror causes hit sharing of parallel tracks
- Direct e-h correlations, e.g. e^+h^- , can be detected by hit proximity and rejected
- Indirect correlations, e.g. e^-h^- cannot be detected \rightarrow they are simulated and subtracted
- Normalization: **absolute** using PHENIX dN/dy of pions

Mixed background normalization

- Like-sign mixed BG normalization:
 - ▣ $FG_{++} = \text{Cross}_{++} + \text{Jet}_{++} + \text{e-h}_{++} + \text{bb}_{++} + \mathbf{nf}_{++} * \text{mixBG}_{++}$
 - ▣ $FG_{--} = \text{Cross}_{--} + \text{Jet}_{--} + \text{e-h}_{--} + \text{bb}_{--} + \mathbf{nf}_{--} * \text{mixBG}_{--}$
- All correlated components calculated on absolute terms
- \mathbf{nf}_{++} and \mathbf{nf}_{--} are determined as the fit parameters in the pair opening angle ($\Delta\phi_0$) region where the correlated backgrounds are smallest
- Unlike-sign normalization: $\mathbf{nf}_{+-} = \sqrt{\mathbf{nf}_{++} \cdot \mathbf{nf}_{--}}$

Quantitative understanding of the background

- Understanding of the background verified by the **like-sign** spectra
 - ▣ Correlated components absolutely normalized
 - ▣ Combinatorial background - mixed background with flow modulations
- The ratio of the like-sign foreground to total background, for $m_{ee} > 0.15$ is **flat at 1**
- **Excellent quantitative understanding of the background**



Analysis

Electron identification

Background subtraction

Cocktail of hadronic sources

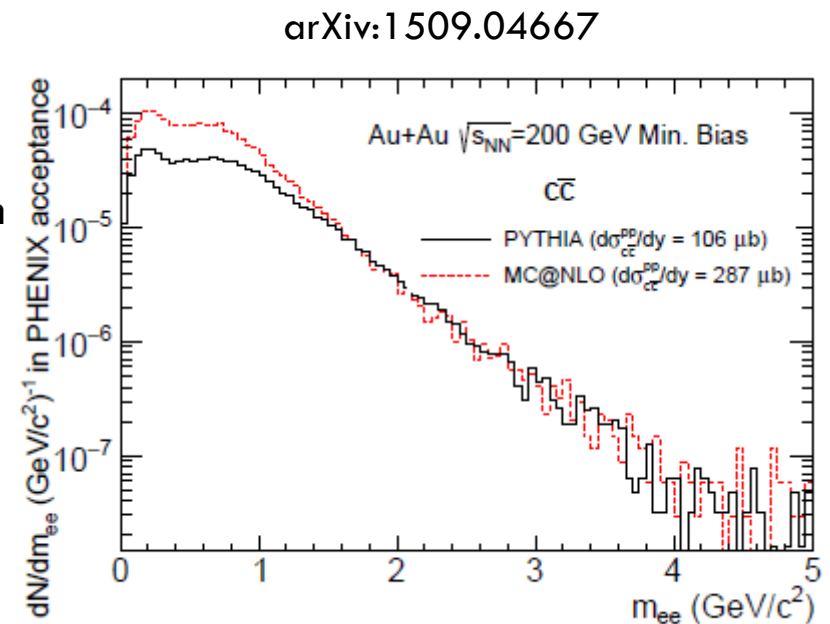


Cocktail of hadronic sources

- Dielectron and Dalitz decay of mesons simulated with EXODUS
 - ▣ π^0 parametrized using modified Hagedorn function
 - ▣ Other mesons(η , ω , ρ , ϕ , J/Ψ): use m_T scaling for the shape and meson to π^0 ratio at high p_T for absolute normalization

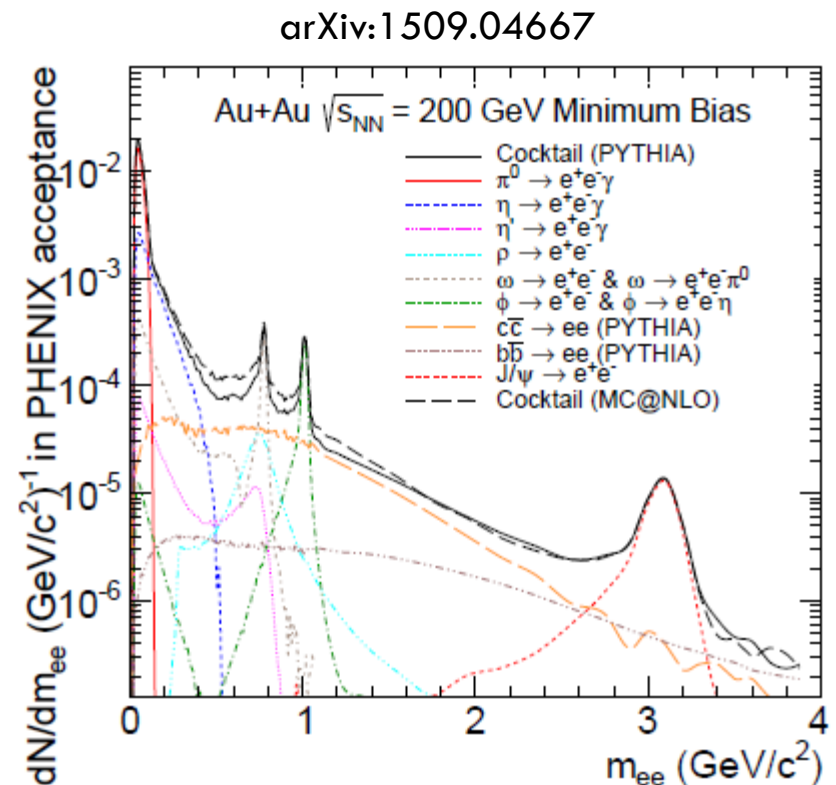
Cocktail of hadronic sources

- Dielectron and Dalitz decay of mesons simulated with EXODUS
 - ▣ π^0 parametrized using modified Hagedorn function
 - ▣ Other mesons(η , ω , ρ , ϕ , J/Ψ): use m_T scaling for the shape and meson to π^0 ratio at high p_T for absolute normalization
- Semileptonic decays of open heavy flavor (c,b) simulated with PYTHIA and MC@NLO
 - ▣ Uncertainty in the charm cross-section and shape - PHENIX PRC 91, 014907 (2015)



Cocktail of hadronic sources

- Dielectron and Dalitz decay of mesons simulated with EXODUS
 - ▣ π^0 parametrized using modified Hagedorn function
 - ▣ Other mesons(η , ω , ρ , ϕ , J/Ψ): use m_T scaling for the shape and meson to π^0 ratio at high p_T for absolute normalization
- Semileptonic decays of open heavy flavor (c,b) simulated with PYTHIA and MC@NLO
 - ▣ Uncertainty in the charm cross-section and shape - PHENIX PRC 91, 014907 (2015)
 - **PYTHIA cocktail** and **MC@NLO cocktail**
- Normalization
 - ▣ In $m_{ee} < 0.1 \text{ GeV}/c^2$ and $p_T/m_{ee} > 5$
 - ▣ Normalize to measured $\pi^0 + \eta + \text{direct } \gamma$

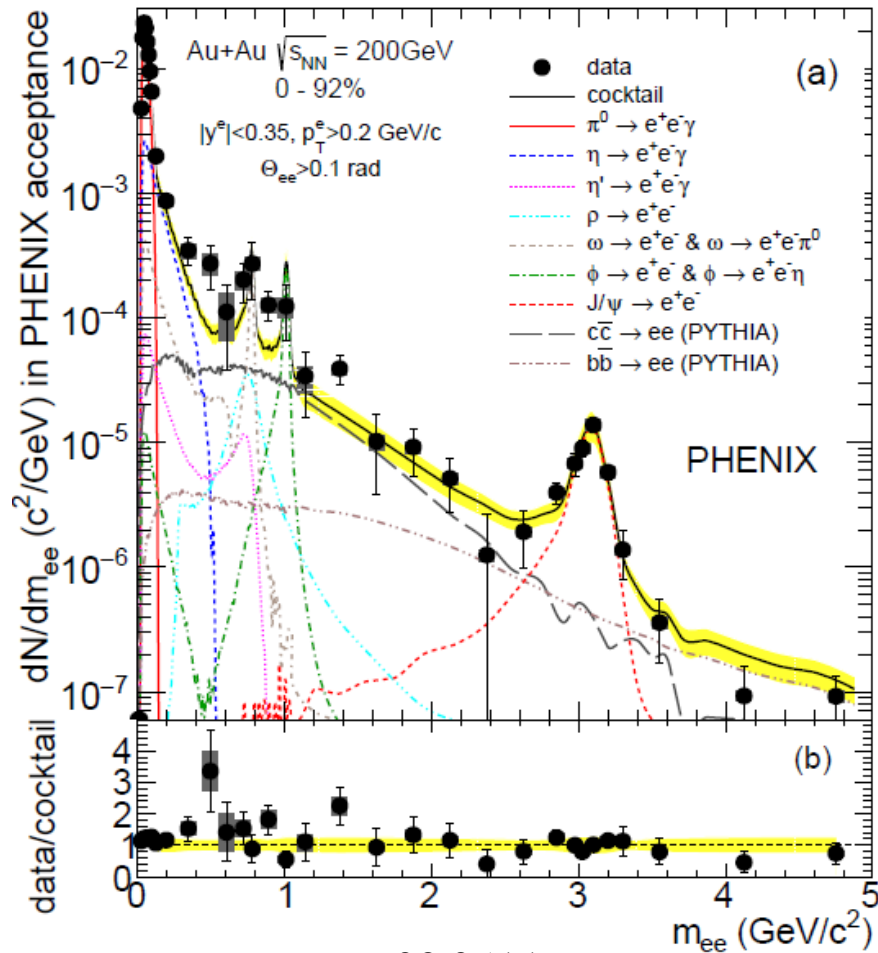


Results



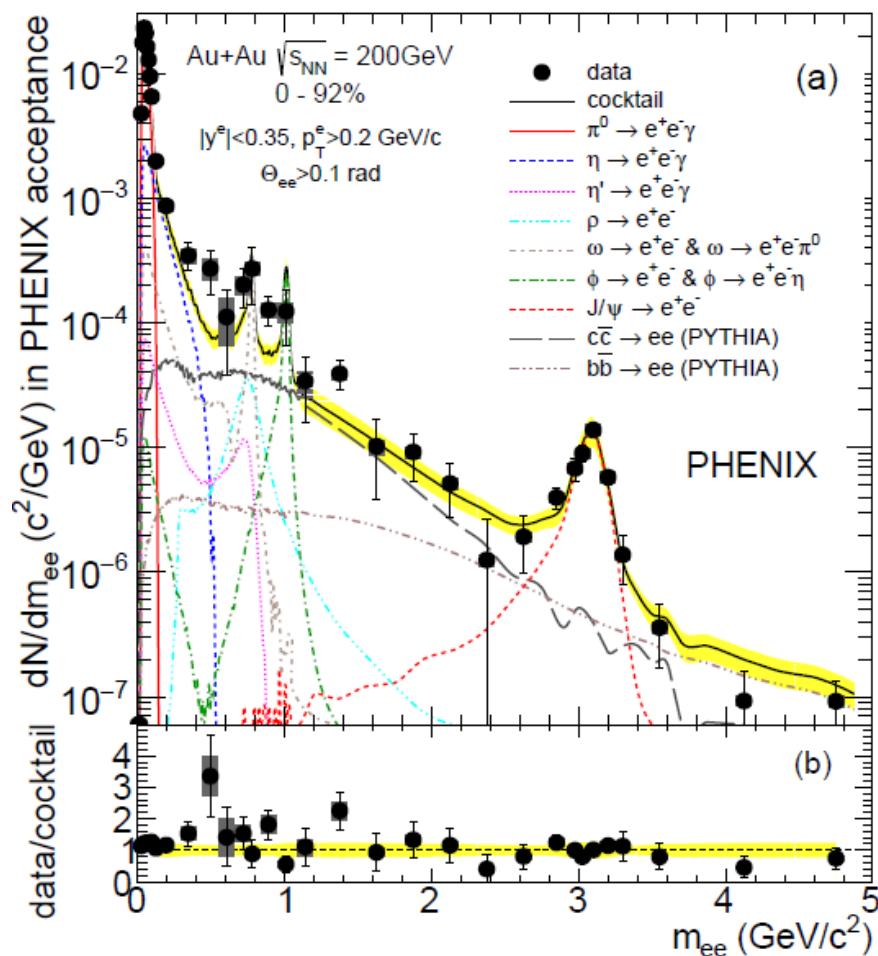
Invariant mass spectra

Minimum bias

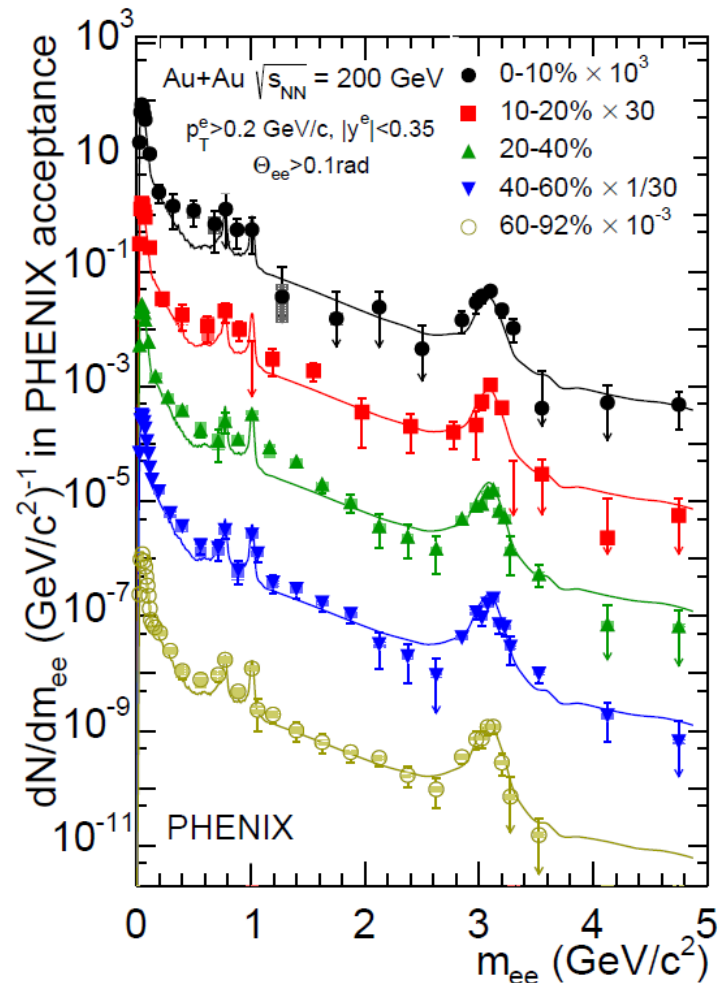


Invariant mass spectra

Minimum bias



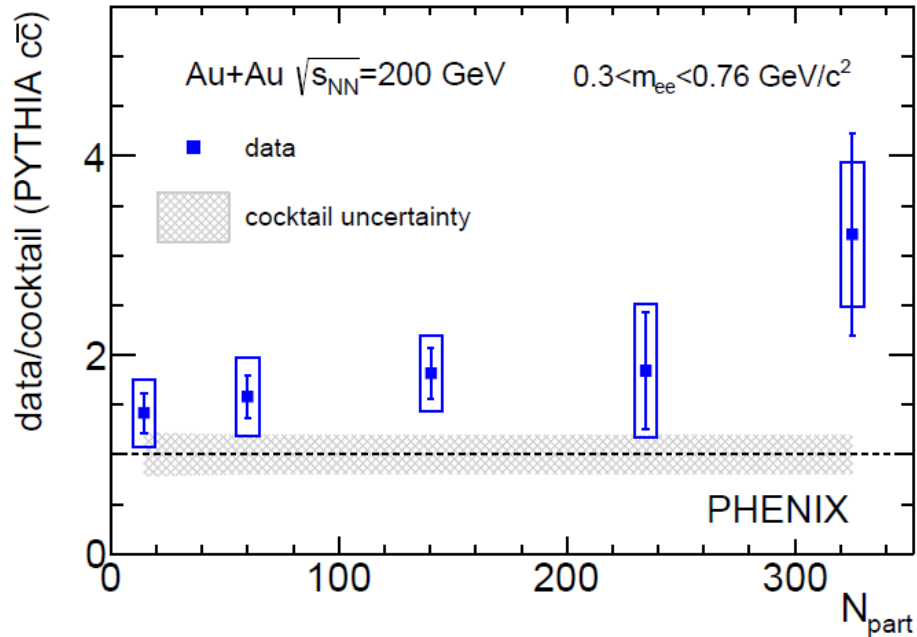
Centrality dependence



Integrated yields (LMR)

Low mass region

$$m_{ee} = 0.3-0.76 \text{ GeV}/c^2$$



arXiv:1509.04667

Data/cocktail in MB ($\pm \text{stat} \pm \text{syst} \pm \text{mod}$):

Pythia: $2.3 \pm 0.4 \pm 0.4 \pm 0.2$

MC@NLO: $1.7 \pm 0.3 \pm 0.3 \pm 0.2$

→ Compatible with STAR results:

$1.76 \pm 0.06 \pm 0.26 \pm 0.33$

PRC92 (2015)024912

Integrated yields (IMR)

Intermediate mass region

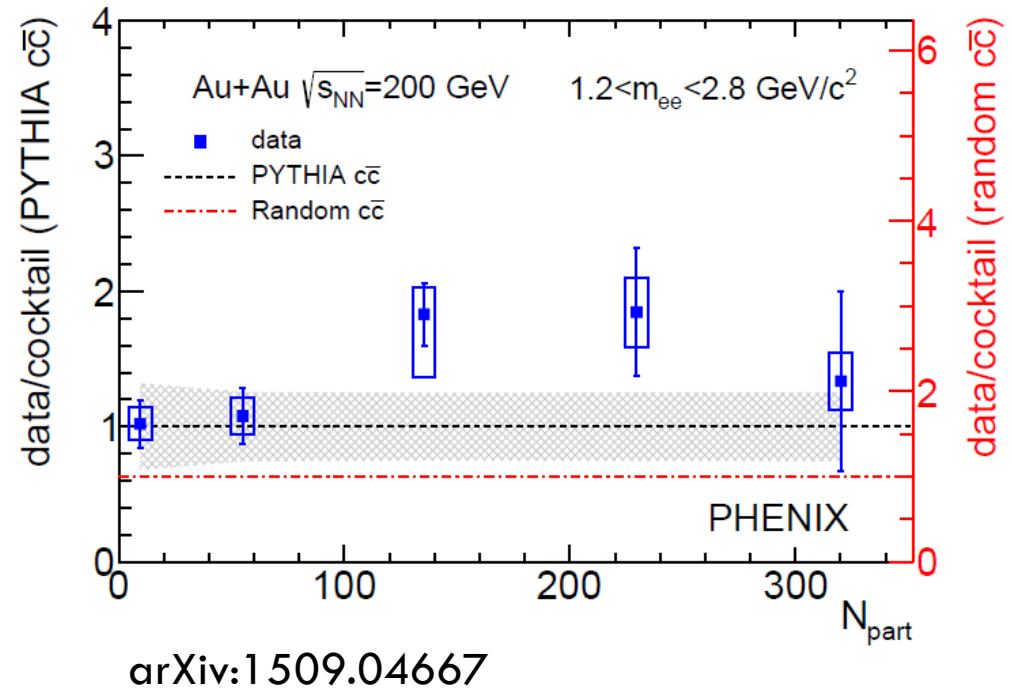
$$m_{ee} = 1.2\text{-}2.8 \text{ GeV}/c^2$$

Data/cocktail in MB ($\pm\text{stat}\pm\text{syst}\pm\text{mod}$):

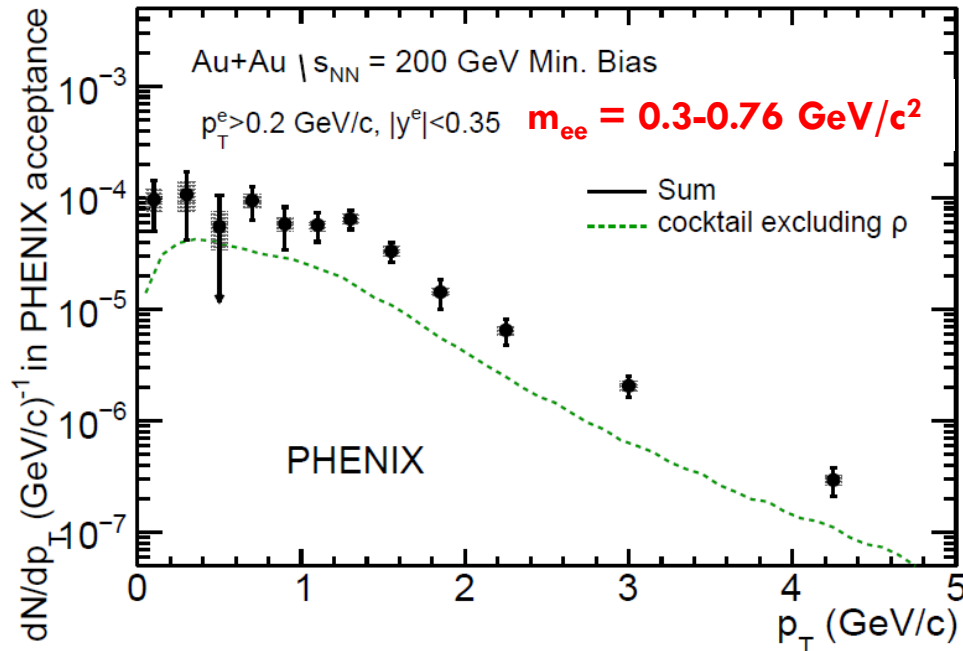
Pythia: $1.3\pm0.7\pm0.2\pm0.3$

Random cc: $2.5\pm0.5\pm0.3\pm0.3$

→ Room for an additional thermal component within uncertainties

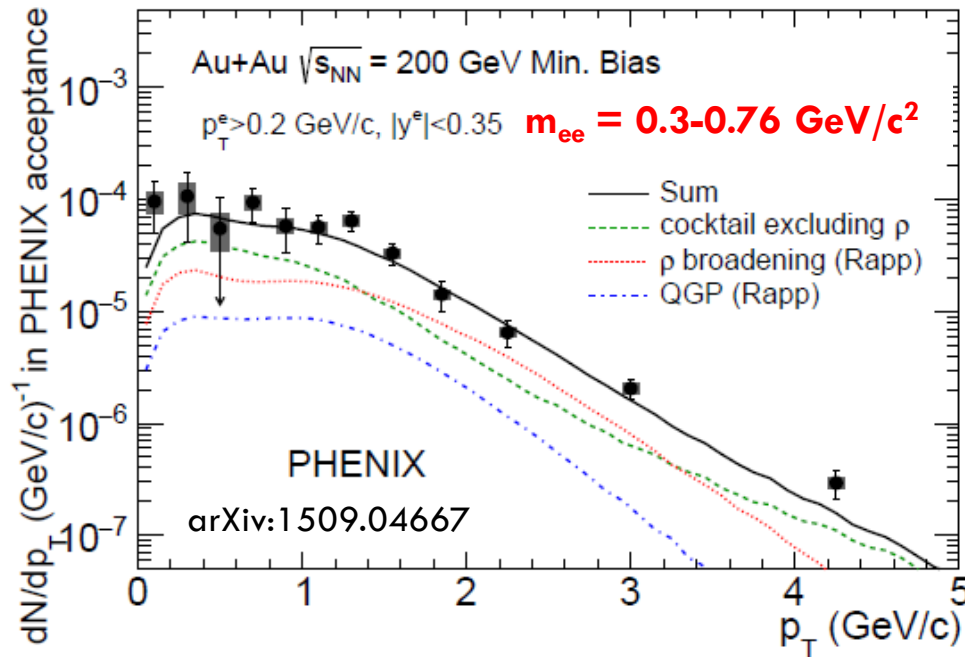


Invariant p_T (Min. Bias)



- Dielectron excess distributed over p_T

Comparison to model (Min. Bias)



- Dielectron excess well described by the model (R. Rapp):
 - In-medium ρ broadening due to scatter off baryons in hadrons gas
 - Little contribution from the QGP

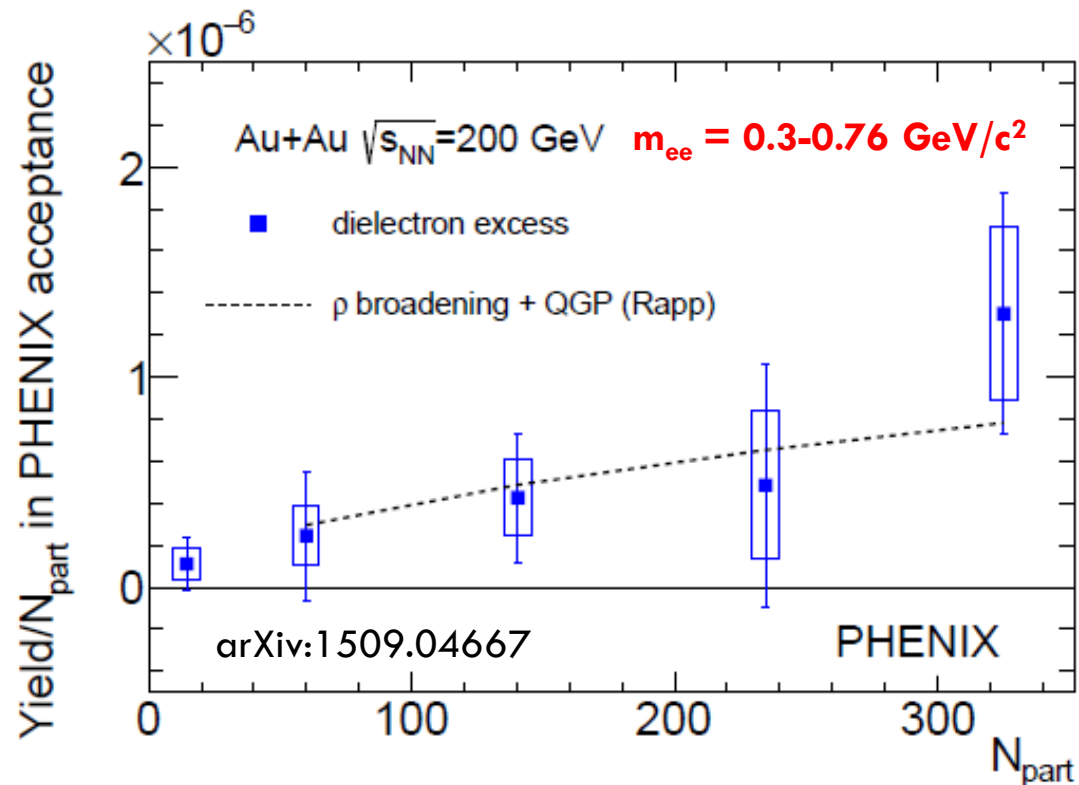
Comparison to model (centrality dependence)

- Centrality dependence of the model consistent with the data

Model yield
scales with:

$$(dN_{\text{ch}}/dy)^{1.45}$$

(R. Rapp)



Summary

- PHENIX provided a new measurement of dielectron invariant yields in Au+Au collisions at 200 GeV
- The new analysis with the HBD
 - ▣ Purity of the electron sample $\geq 95\%$
 - ▣ Background described qualitatively and quantitatively to an excellent level
 - ▣ Cocktail: uncertainty in the charm contribution (PYTHIA vs. MC@NLO)
- Results
 - ▣ LMR: enhancement consistent with in-medium rho broadening
 - ▣ IMR: room for a thermal source beyond the cocktail



BACKUP

PHENIX Time-of-flight

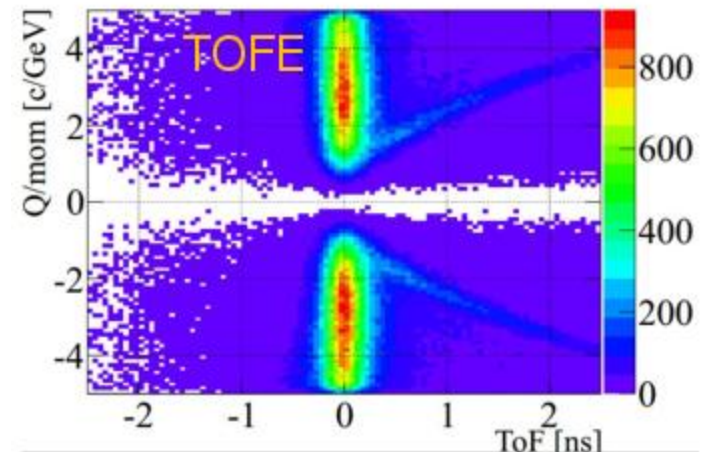
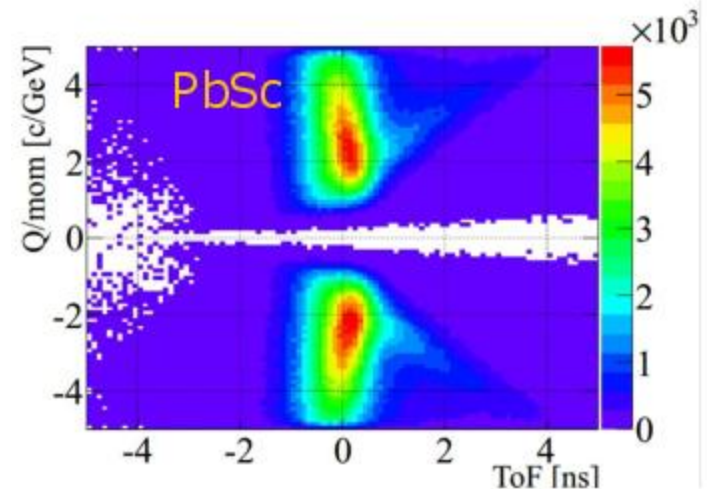
- Time-of-flight information implemented for improved hadron rejection

- EMCal (PbSc)

- 3/4 of acceptance
- $\sigma=450$ ps

- ToF East

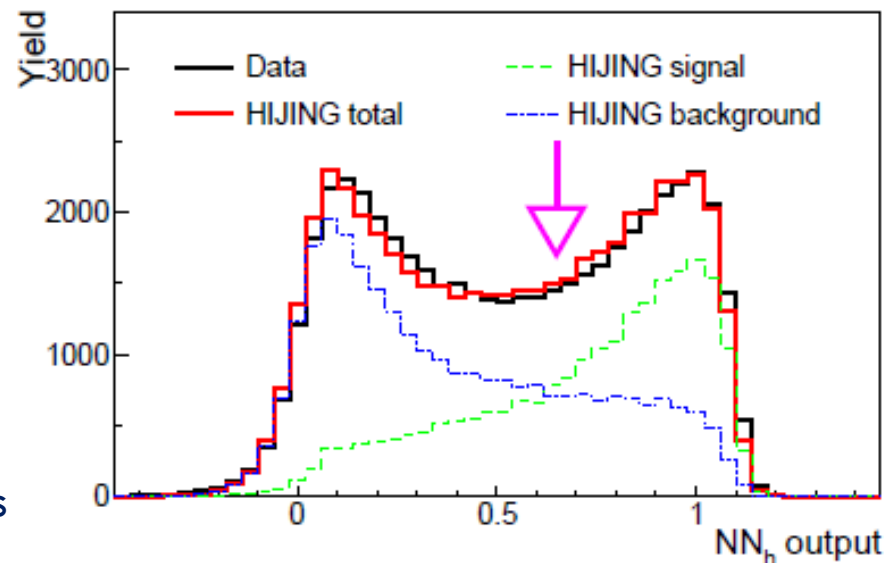
- $\sim 1/8$ of acceptance
- $\sigma=150$ ps



Electron identification with neural networks

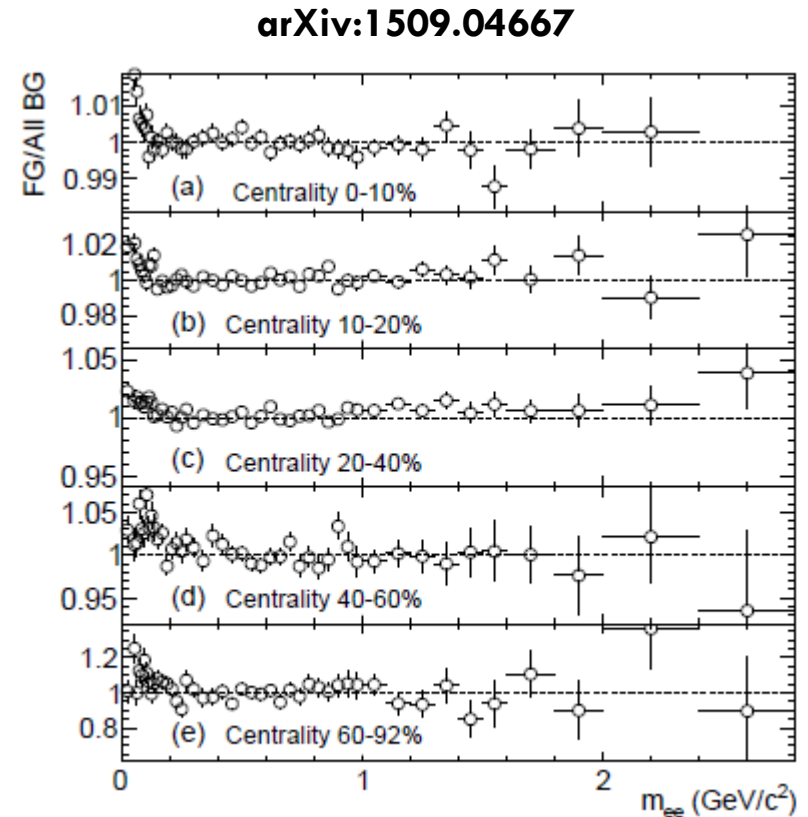
- Use reconstructed parameters from RICH, EMCAL, HBD, ToF as NN inputs
- Train and monitor NNs using simulations
- Use separate neural networks for:
 - Hadron rejection
 - Conversion rejection
 - HBD double hit rejection
- **Achieve electron sample purity for all centralities $\geq 95\%$**
- Was $\sim 70\%$ in Run-4 with 1D eID cuts in MB collisions

Example: hadron rejection
NN for 0-10% centrality

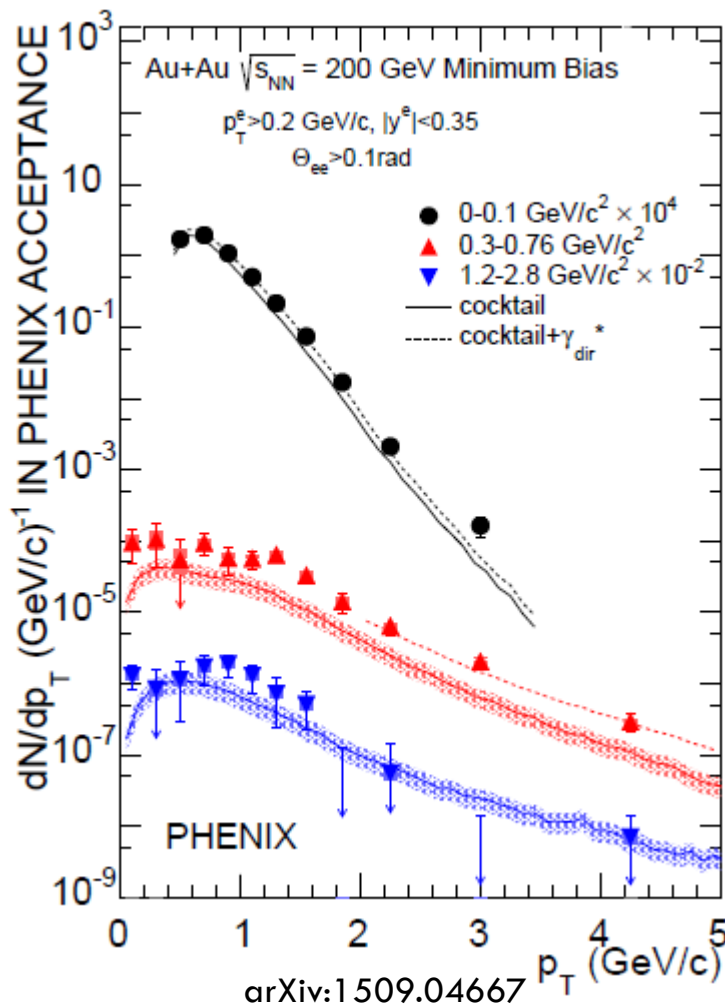


Quantitative understanding of the background

- Understanding of the background verified by the **like-sign** spectra
- Correlated components absolutely normalized
- Combinatorial background - mixed background with flow
- The ratio of the like-sign foreground to total background, for $m_{ee} > 0.15$ is **flat at 1**
- **Very good quantitative understanding of the background**



Dielectron invariant p_T (Min. Bias)



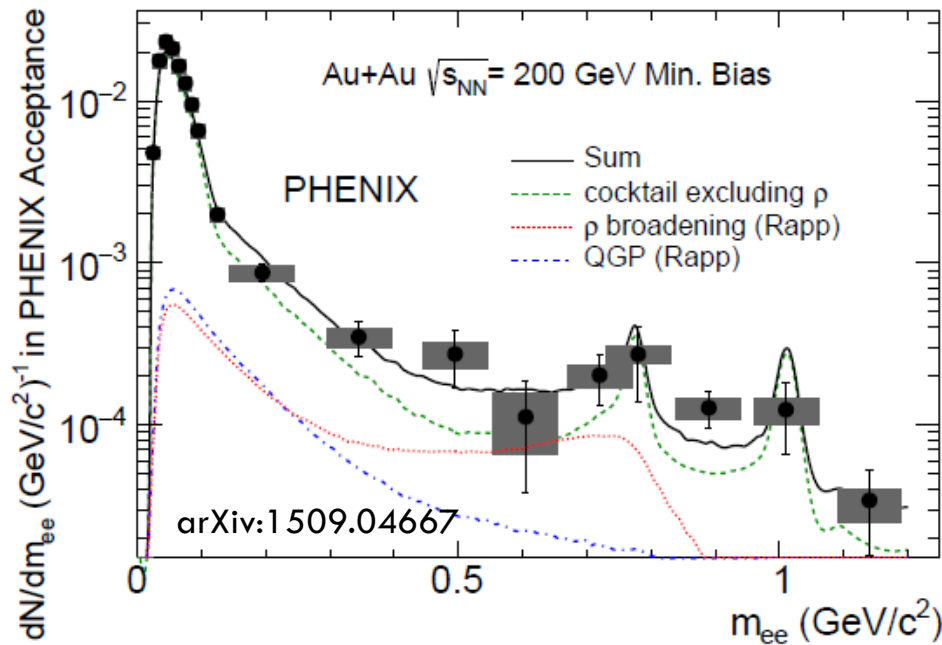
□ Invariant p_T yield in m_{ee} :

□ 0 - 0.1 GeV/c²

□ 0.3 - 0.76 GeV/c²

□ 1.2 - 2.8 GeV/c²

Comparison to model (Min. Bias)



- Dielectron excess well described by the model (R. Rapp):
 - In-medium ρ broadening due to scatter off baryons in hadrons gas
 - Little contribution from the QGP

Systematic uncertainties

□ For Minium bias collisions

Component	Uncertainty
eID+occupancy	$\pm 4\%$
Acceptance (time)	$\pm 8\%$
Acceptance (data/MC)	$\pm 4\%$
Combinat. backgr. (0-5 GeV/c ²)	$\pm 25\%$ (at 0.6 GeV/c ²)
Residual yield (0-0.08 GeV/c ²)	- 5% (at 0.08 GeV/c ²)
Residual yield (1-5 GeV/c ²)	- 15% (at 1.0 GeV/c ²)

Comparison to previous PHENIX analysis

- **Hadron contamination:** was 30%, now 5% in MB
- **Signal sensitivity:** a factor of ~ 3.5 improvement in 0.15-0.75 GeV/c²
- **Pair cuts:** now stronger pair cuts fully remove detector correlations
- **Flow:** now included in the shape of the mixed BG
- **e-h pairs:** now subtracted
- **Jets:** oposite jets component now explicitly subtracted
- **Background subtraction:** all correlated components calculated and subtracted on absolute terms

Parallel analysis

- Independent analysis to provide a consistency check
- Key differences are:
 - ▣ Different HBD reconstruction algorithm
 - ▣ eID with 1D cuts
 - ▣ Normalization of background components by simultaneous fit to the like-sign spectra
- Features:
 - ▣ Electron purity $\sim 85\%$ in 0-10% cent.
 - ▣ Signal sensitivity in LMR ~ 0.5 compared to than the main analysis
- Result: consistent with the main analysis

